Diagnosis of Flow and Magnetic Fields Using Simultaneous Spectro-Polarimetry of Photospheric Fe\textsc{i} and Chromospheric Mg\textsc{i} lines

Na Deng,\textsuperscript{1} Debi Prasad Choudhary,\textsuperscript{1} and K. S. Balasubramaniam\textsuperscript{2}

\textsuperscript{1}California State University Northridge, Physics and Astronomy Department, 18111 Nordhoff St., Northridge, CA 91330, USA

\textsuperscript{2}USAF/Air Force Research Laboratory, Solar Disturbances Prediction, P.O. Box 62, Sunspot, NM 88349, USA

Abstract. We present a study of active region (AR) NOAA 9661 using simultaneous spectro-polarimetric observations of photospheric Fe\textsc{i} (630.25 and 630.15 nm) and chromospheric Mg\textsc{i} b\textsubscript{2} (517.27 nm) lines obtained with the HAO/NSO Advanced Stokes Polarimeter (ASP). SIR (Stokes Inversion based on Response function) code was applied to the Stokes spectra of Fe\textsc{i} line pair and Mg\textsc{i} line, thus providing magnetic field vectors at the photosphere and low chromosphere. We quantitatively compared the magnetic field at the two heights and obtained reasonable results. Doppler velocities were extracted from both Stokes I and V profiles of the three spectral lines, which reveal strong red shifts in the penumbra near the magnetic neutral line.

1. Introduction

Simultaneous spectro-polarimetry of multiple spectral lines that are formed at different atmospheric heights can provide direct information to diagnose the three-dimensional (3D) structure of flow and magnetic fields. Benefiting from advances in observational instruments and analysis techniques, such approach has recently been applied to both quiet Sun and active regions (e.g., Zhang & Zhang 2000a,b; Choudhary et al. 2001; Gosain & Choudhary 2003; Leka & Metcalf 2003; Nagaraju et al. 2008).

2. Observation and Data Reduction

We observed a near disk-center AR NOAA 9661 (N14°, W6°, \(\mu = 0.96\)) using the 76 cm Dunn Solar Telescope in conjunction with the ASP (Elmore et al. 1992; Lites 1996) on 2001 October 17. Full Stokes spectra of aforementioned three spectral lines were taken simultaneously. Their formation heights span from photosphere to the low chromosphere (Khomenko & Collados 2007; Lites et al. 1988; Briand & Solanki 1995). The spectral dispersions for Fe\textsc{i} line pair and Mg\textsc{i} line are 1.27 and 1.02 pm pixel\(^{-1}\), respectively.

The data were calibrated using the standard ASP calibration routines (Lites et al. 1991; Skumanich et al. 1997). The calibrated Stokes \(I, Q, U, V\) spectra were normalized to the quiet Sun continuum intensity at Sun center (\(I_{qs,c}\)) before inverted by the
SIR code (Ruiz Cobo & del Toro Iniesta 1992). Although the SIR code works under LTE assumption, we also applied it to Mg line that is formed near the temperature minimum region, where non-LTE effect is not negligible but not as significant as in the typical chromosphere. The azimuthal ambiguity of the inverted magnetic field was resolved using the minimum energy algorithm (Metcalf 1994). The projection effect was also corrected so that the magnetic field vector is presented in the local Cartesian coordinates.

3. Result

Figure 1 indicates that SIR code provides good fit to both Fe line pair and Mg line. The observed polarimetric spectra of Mg line are much noisier than those of Fe lines, which may be due to (1) weaker magnetic field, (2) less photon, and (3) more dynamic nature in the chromosphere.

Figure 2 shows the inverted magnetic field vectors at the photosphere (Fe) and low chromosphere (Mg). The signal-to-noise (S/N) ratio of the Mg maps is lower than Fe maps especially in umbral areas, where the low light level results in noisy spectrum although the magnetic field is strong at these locations. The total magnetic flux in the Fe and Mg Bz maps are \(2.15 \times 10^{22}\) and \(1.82 \times 10^{22}\) Mx, respectively, with a difference of about 15%.

Figure 3 illustrates the comparison of the magnetic field at two heights. The scatter plot between \(B_z\) (Fe) and \(B_z\) (Mg) can be divided into several sections as illustrated by the dotted vertical lines. The central section corresponds to \(B_z\) (Fe) between \(-300\) and \(300\) G, i.e., weak magnetic field region outside the solid contours shown in Figure 2. The slope of the linear fit of this section is 2.83, which indicates a stronger \(B_z\) in the low chromosphere than in the photosphere at locations outside strong magnetic fluxes. This can be explained in terms of the magnetic canopy effect. The lateral two sections correspond to \(|B_z|\) (Fe) between 300 and 1500 G, i.e., regions between the solid and dotted contours in Fig. 2. They have slopes of 0.23 and 0.3, which implies that the magnetic strength decreases rapidly with height in those regions. The outermost two sections correspond to umbral areas with \(|B_z|\) (Fe) larger than 1500 G, where the Mg data are not well inverted due to low S/N ratio. The histograms of magnetic field inclination angles show that the near vertical positions (0° or 180°) have more population in the Mg map compared to the Fe map, which suggests that the magnetic field lines become more vertical at higher altitude.
Figure 2. The columns from left to right are vertical magnetic field component $B_z$, transverse magnetic field component $B_t$ represented by the length and direction of the arrows, and magnetic field inclination angle $\gamma$ with respect to the surface normal, at two atmospheric layers obtained from the SIR inversions of the Fe I line pair (photosphere; bottom panels) and the Mg I line (low chromosphere; top panels). The solid and dotted contours correspond to $|B_z|$ (Fe I) of 300 and 1500 G, respectively.

Figure 3. Left panel: Scatter plot between $B_z$ (Fe I) and $B_z$ (Mg I). Linear fittings were applied to the central three sections and their slopes (k) are labeled aside. Right panel: Histograms of magnetic field inclination angles in the FOV.

Figure 4 reveals the variation of Evershed flow with height. As an example, we compute the mean Doppler velocities for a center-side penumbra region (white box), which shows a chromospheric reversal. For a compact penumbral region near the magnetic neutral line of the $\delta$ spot, apart from noise dominating the Fe I 630.25 $\nu_i$ signal, all the Dopplergrams show strong red shifts with a mean speed ($\sim$0.6–3 km s$^{-1}$) significantly larger than that of the ordinary Evershed flows ($\sim$0.2–0.6 km s$^{-1}$ in the white box). Noticeably, the strength of the red shifts decreases with height.

4. Conclusion

The present study deduced vector magnetic fields at two heights by applying the SIR code on simultaneous spectro-polarimetric observations of multiple lines. The results are reasonable in most aspects. Further efforts are being undertaken to investigate the 3D magnetic field, especially the strong red shift regions near the magnetic neutral line.
Figure 4. Dopplergrams derived from Stokes $I$ line center shifts ($\nu_i$) and Stokes $V$ zero-crossing shifts ($\nu_{zc}$) for the three spectral lines arranged from left to right columns by following the order of their formation heights. The numbers are the mean velocities (in unit of km s$^{-1}$) within the strong red shift region near the magnetic neutral line of the $\delta$ spot, and those in the penumbral region outlined by the white box. The spatial points with noisy and abnormal profiles are assigned a value of 0.

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References